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Liquefaction Potential of the Sacramento-San Joaquin Delta

by
Michael O. Finch[1]

ABSTRACT

This geotechnical study assessed the potential for liquefaction along the Sacramento-San Joaquin Delta levee system, which holds back salt water from San Francisco Bay to the west. A catastrophic failure of this system could pollute the Delta's fresh water upon which much of California depends. Since 1850, oxidation of the Delta's peat soils has caused subsidence on over 740,000 acres. Today, Delta elevations range as low as 25 feet below sea level and continue to sink at average rates of up to three inches per year. Delta levees also experienced record high water levels five times in the last ten years.

Several aqueducts and canals divert much of the Delta's fresh water to surrounding regions, and provide water to two thirds of California's population and one quarter of its land area.

Several major active faults pass near or through the Sacramento-San Joaquin Delta. The Delta has not experienced severe seismic shaking since the great 1906 San Francisco earthquake, however, recent moderate earthquakes have produced non-catastrophic Delta levee damage.

This study found liquefiable sand to be widespread beneath the levee systems on most of the 70 major Delta islands. The susceptibility of the Delta levees to earthquake-induced liquefaction is high. Because of the high probability of large earthquakes in the Bay region in the coming decades, the potential for liquefaction here also is high. Therefore, the risk of catastrophic levee failure caused by earthquake-induced liquefaction and the resulting loss of the Delta's freshwater resource, is high. Unless it is mitigated, this risk will increase with continued Delta subsidence and global sea level rise.

INTRODUCTION

The Sacramento-San Joaquin Delta is located at the confluence of the Sacramento and San Joaquin rivers, immediately upstream from the San Francisco Bay system. Nearly one-half of California's total river volume passes through the Delta (U.S. Army Corps of Engineers, 1982). Starting in 1940, part of this flow was diverted for municipal and agricultural use. At present, six major aqueducts and canals deliver Delta water as far south as the Mexican border and as far west as San Francisco. Nearly 90 public agencies, serving over two-thirds of California's population and more than one-quarter of its land area, contract for Delta water (McClurg and others, 1978).

This freshwater resource has a seismic risk that includes: (1) the potential earthquake damage to the Delta's levee system and consequent pollution of freshwater supplies by intruding salt water from the Bay; and (2) earthquake damage to the aqueducts that transport this freshwater to much of the state's population. This paper addresses the potential for earthquake-caused damage to the Delta's levee system.

HISTORY OF DELTA DEVELOPMENT

Before 1850 the Delta was a tideland swamp with low tule covered islands that were just awash at high tide (Thompson, 1982). With the passage of the Arkansas Swamp Act in 1850, the Federal Government granted to the states all swamp and tidelands that could be drained and reclaimed. The California Legislature passed the Green Act in 1868, which removed all controls on the reclamation process, and widespread reclamation began in the Delta. Private citizens gained title to unreclaimed land by paying a small filing fee (usually one dollar per acre) and building low levees around the area to hold back tidal waters. After the land dried, landowners stripped the islands of their native vegetation, usually by burning. Up to two feet of peat soil were lost in a single burning.

The islands were intensively farmed for cash crops that included potatoes and white asparagus requiring loose, well tilled soils. Delta soils are also low in potassium, and farmers often burned the peat to increase soil nutrients. These farming practices led to subsidence due to oxidation, dewatering, and deflation. Subsidence continues today in

[1] California Integrated Waste Management Board, 8800 Cal Center Drive, Sacramento, CA 95826-3268

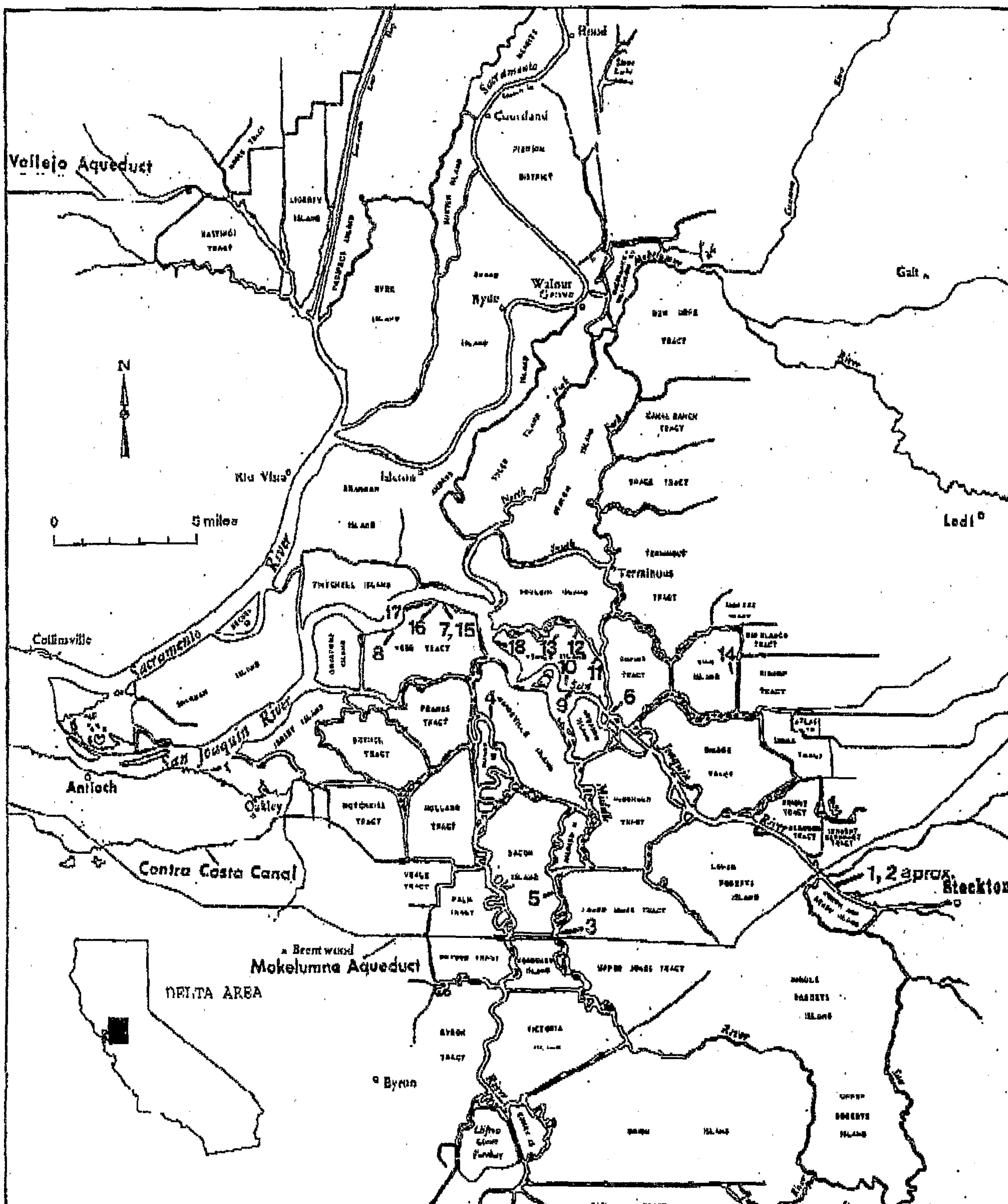

Figure 1. Sacramento-San Joaquin Delta earthquake damage sites. Earthquake damage areas numbered 1-18 correspond to sites numbered in Table 1.

Table 1. Earthquake related damage, Sacramento-San Joaquin Delta.

Site No.	Epicenter	Date	Magnitude	Delta Island or Tract	Distance to Fault Rupture	Aprox.* *max in miles	Damage
1	Winters-Vaccavile	4-19-92 4-21-92	6.2 6.4	Weber Tr	60	0.06	Cracks and slip-outs**
2	San Francisco	4-18-06	8.3	Weber Tr.	70	0.16	Cracks and slip-outs**
3	Pittsburg	10-24-55	5.0	Lower Jones Tr.	20	0.05	1000-foot long cracks along levee crown near to some trees.
4	Coyote	8-6-79	5.9	Mandeville Is.	65	0.03	A 500-foot section of the levee moved landward several feet. It was noticed independently by two people. First seen minutes after the quake.
5	Livermore	1-24-80	5.9	Bacon Is.	20	0.10	A 250-foot land-side slip-out dropped several feet. Sited in Kearney, 1980.
6	Livermore	1-24-80	5.9	Empire Tr	20	0.10	A 200-foot land-side slip-out dropped 6 inches. Reported by local resident and DWR employee.
7	Coalinga	5-2-83	6.7	Webb Tr.	150	0.01	A 500-foot long crack opened along levee crown up to 5 feet wide. Five slip-outs. Bulldozer rolled off levee. Several eyewitnesses at time of quake. Levee nearly failed according to foreman present.
8	Coalinga	5-2-83	6.7	Webb Tr	150	0.01	The "Garratt Well" an abandoned artesian well, and the site of seepage for years stopped flowing after the earthquake.
9	Coalinga	5-2-83	6.7	Venice Is.	150	0.01	A 500-foot long crack opened along levee toe and dropped from several inches to over 2 feet. Damage noticed minutes after earthquake.
10	Coalinga	5-2-83	6.7	Venice Is.	150	0.01	An area of persistent seepage for many years stopped after the quake.
11	Coalinga	5-2-83	6.7	Venice Is.	150	0.01	Several cracks opened - one was 400 feet long and had water pouring out.
12	Coalinga	5-2-83	6.7	Venice Is.	150	0.01	A 1000-foot long crack ran along the levee toe. It was several inches to 3 feet wide.
13	Coalinga	5-2-83	6.7	Venice Is.	150	0.01	At this site 14 wooden pilings popped up in a field that had been mowed the day before. The pilings were the foundations of an abandoned horse barn.
14	Coalinga	5-2-83	6.7	King Is.	150	0.01	The concrete floor of a shed cracked for 25 feet and settled 8 inches.
15	Pittsburg	6-5-83	3.6	Webb Tr.	15	0.02	Several minor cracks were noticed at the Coalinga damage site 7. These cracks were at right angles to those produced by the Coalinga event.
16	Morgan Hill	4-24-84	6.2	Webb Tr.	60	0.05	Six parallel cracks one inch wide and 75 feet long were noticed minutes after the earthquake.
17	Morgan Hill	4-24-84	6.2	Webb Tr.	60	0.05	A 25-foot long one inch wide crack.
18	Morgan Hill	4-24-84	6.2	Venice Is.	60	0.05	A pre-existing 25-foot long crack lenghtened 75 feet along the levee and the land side dropped 2 inches. Site inspected before and after the earthquake by DWR employees.

* Maximum Acceleration in g's

** From a letter written by Weber's engineer in c1914

After Finch, 1985.

the Delta, mostly as a result of oxidation, at rates of up to 4.6 inches per year with an average loss of 3.0 inches per year in the central Delta (Newmarch, 1980). Over 740,000 acres of the Delta have sunk since 1850 requiring the construction of nearly 1000 miles of levees. Presently over 200,000 acres of the Delta measure below sea level with elevations as low as minus 25 feet (Rote, 1982). Landowners raised levees as the land sank and today some exceed 30 feet in height (U.S. Army Corps of Engineers, 1984). Tidal surges and high river flows led to record high water levels in the Delta five times in the last ten years: 1982, twice in 1983, and twice in 1986. Studies of modern changes in global sea level indicate that the Delta levees are facing a rise in sea level of 4 to 5 inches per decade (Williams, 1985).

HYDROLOGY OF THE DELTA

The Delta is hydrologically complex. Several major rivers including the Sacramento, San Joaquin, Calaveras, Consumnes, and Mokelumne, join to form a single channel at Chipps Island. Prior to California's water development, the Delta was predominately a freshwater swamp, but during periods of low river flow in the summer, salt water backed up into Suisun Bay and into the Delta (Jackson and Paterson, 1977). This consequence was pronounced in low rainfall years. The worst case of documented salt water intrusion occurred in September, 1931, when concentrations of 1000 ppm chloride reached as far north as Freeport and as far south as Tracy.

The recognition of the Delta as a "common pool" for water users led to the realization of its vulnerability to salt water intrusion. In June, 1972, a sudden levee failure on Brannan-Andrus Island drew up salt water from Suisun Bay into the Delta. Some 300,000 acre-feet of freshwater was released from upstream dams in a vain attempt to control the salinity intrusion and 53,000 tons of additional salts were pumped from the Delta into export canals (Jackson and Paterson, 1977). In a 1982 report to the California Legislature, the Emergency Delta Task Force identified levees as crucial for maintaining Delta water quality. Without the integrity of its levee system, the Delta will eventually flood and transform into a shallow, inland, saline bay (Rote, 1982).

FAULTING NEAR THE DELTA

Several active faults with damaging earthquake potential pass through or near the Delta. The more prominent faults include: (1) the Antioch fault; (2) Calaveras fault; (3) Green Valley or Concord faults; (4) Greenville fault; (5) Hayward fault; (6) Rodgers Creek fault; (7) Sierran Block Boundary Zone (or Winters-Vacaville) fault; and (8) San Andreas fault. The Hayward, Rodgers Creek, and San Andreas faults, alone, are reported to have a 67% probability of generating at least one magnitude 7 earthquake before the year 2020 (WGCEP, 1990).

Other faults such as the San Gregorio (Seal Cove) fault, and the Foothills (Bear Mountain) fault system, may inflict lesser degrees of damage to the Delta because of their greater distance. The Rio Vista-Sherman Island fault, Midland fault, and Tracy-Stockton fault do not appear to be active (Newmarch, 1985).

EARTHQUAKE-INDUCED LEVEE DAMAGE

Earthquakes are not known to have caused catastrophic Delta levee failures. The Delta, however, has experienced only limited seismic shaking since the first levees were constructed in 1850. The great San Francisco earthquake of 1906 shook the Delta more severely than any other since reclamation began. Only limited damage occurred then because subsidence had not yet become a major problem for levee stability. Also, because Delta elevations in 1906 measured significantly higher than today (from sea level to approximately five feet below sea level), few levees exceeded five feet in height. However, many Delta bridges and railroad embankments sank to some extent coincident with the 1906 earthquake (Kearney, 1980).

Finch (1985) published the first compilation of damage to Delta levees from weak and distant earthquakes. Eighteen examples of earthquake damage are now documented (Table 1 and Figure 1). Estimates of on-site peak accelerations at those sites suggest seismic amplification from the Delta's saturated, unconsolidated sediments (Finch, 1987). Eight of the twelve most recently damaged sites listed on Table 1 are underlain by low density, potentially liquefiable sands: site numbers 7, 9, 11, 12, 15, 16, 17, and 18. Sandy, saturated sediments are particularly susceptible to liquefaction during earthquakes.

SEISMIC ANALYSIS OF DELTA LEVEES

Over the last ten years the use of sand in repairs of Delta levees became a common practice. Suction dredges place loose sands on levee crowns, backslopes, and toes. Levee breaks are also repaired with loose sand. In 1985, the author sampled through sandy levee sections on 59 of the 70 major Delta islands with a 10-foot hand auger. The test holes revealed uniform, medium-grained sands with low relative densities and low standard penetration blow counts (Table 2). Saturated conditions were present in all of the borings. These findings together indicate a high susceptibility to widespread earthquake-induced levee failure from a major earthquake centered in or near the Delta.

Table 2. Tabulation of liquefaction potential data: Sandy levee sections on Delta islands with low relative densities and blow counts indicating high susceptibility to liquefaction (see text).

Delta Island/Tract	Relative Density	Standard Blow Count
Atlas		9 at 9.4 feet
Bacon	26% at 6.2 feet	5 at 6.0 feet
Bethel	16% at 7.0 feet	5 at 7.9 feet
Bishop		9 at 9.4 feet
Bouldin	35% at 6.0 feet	10 at 19 feet
Brack		5 at 5.0 feet
Bradford	20% at 7.1 feet	4 at 17 feet
Brannan-Andrus	13% at 5.0 feet	2 at 7.0 feet
Byron	30% at 7.0 feet	5 at 6.0 feet
Canal Ranch		2 at 15 feet
Coney		6 at 12 feet
Drexler		9 at 15 feet
Egbert	13% at 17.3 feet	
Empire		4 at 6.0 feet
Fabian		5 at 8.0 feet
Grand	32% at 8.0 feet	4 at 2 3 feet
Hastings		5 at 5.0 feet
Holland	14% at 6.5 feet	4 at 15 feet
Hotchkiss	13% at 5.0 feet	5 at 5 .5 feet
Jersey	8% at 4.5 feet	3 at 16 feet
Jones: Upper-Lower	15% at 7.0 feet	1 at 7.5 feet
King		3 at 7.0 feet
Liberty	10% at 4.0 feet	3 at 7.0 feet
Mandeville	10% at 4.8 feet	3 at 15 feet
McCormack-William.		6 at 7.0 feet
McDonald	30% at 3.0 feet	8 at 17 feet
Medford		3 at 7.0 feet
Merritt		4 at 18 feet
New Hope		7 at 5.0 feet
Orwood	27% at 6.5 feet	4 at 7.1 feet
Palm	35% at 7. feet	4 at 23 feet
Pierson		2 at 20 feet
Prospect	23% at 5.7 feet	3 at 6.5 feet
Quimby		5 at 18 feet
Rindge		2 at 15 feet
Rio Blanco		7 at 5. feet
Roberts: Up/Mid/Low	34% at 5.0 feet	4 at 7.0 feet
Ryer	30% at 7. feet	3 at 27 feet
Sargent-Barnhart		4 at 10 feet
Sherman	19% at 6.8 feet	4 at 7.0 feet
Shima		10 at 10 feet
Shin Kee		7 at 5.0 feet
Staten		2 at 10 feet
Sutter	20% at 5.2 feet	2 at 18 feet
Terminous		4 at 7.0 feet
Twitchell	32% at 10 feet	6 at 10 feet
Tyler		2 at 10 feet
Union	30% at 5.5 feet	3 at 6.4 feet
Upper Orwood		3 at 10 feet
Van Sickle		4 at 6.5 feet
Venice	30% at 5.1 feet	1 at 12 feet
Victoria	21% at 6.7 feet	3 at 7.0 feet
Webb	34% at 4.8 feet	4 at 32 feet
Woodward	14% at 6.4 feet	3 at 7.0 feet
Wright-Elmwood		2 at 10 feet

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CONCLUSIONS

The Sacramento-San Joaquin Delta remains California's most important water resource. Levees in the Delta hold back salt water from San Francisco Bay and protect the Delta's water quality. Several faults capable of large earthquakes pass through or near the Delta. Recently, earthquakes of only moderate strength and on distant faults have damaged Delta levees. An analysis of nearly all of the Delta's levee systems revealed a high susceptibility to widespread earthquake induced liquefaction from a major earthquake. Because the probability for major earthquakes in the Bay region is known to be high, the potential for earthquake-induced liquefaction in the Delta is also high. Therefore, the seismic risk to the Delta levee system and the freshwater resource it protects appears to be high. Without future mitigation, this risk will increase with continued Delta subsidence and global sea level rise.

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